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Claims

[c1] 1. A process for producing a rotor, the process comprising the steps of:
casting an ingot to have at least first and second ingot regions axially aligned within the ingot, the first and second ingot regions being formed of different alloys that intermix during casting to define a transition zone between the first and second ingot regions, the transition zone having a composition that differs from and varies between the first and second ingot regions;
forging the ingot to produce a rotor forging containing first and second forging regions and a transition zone therebetween corresponding to the first and second ingot regions and the transition zone of the ingot such that the first and second forging regions are formed of the different alloys and the transition zone of the rotor forging has a composition that differs from and varies between the first and second forging regions, the first and second forging regions and the transition zone therebetween being axially aligned along a geometric centerline of the rotor forging, the transition zone of the rotor forging being asymmetrical about the geometric centerline of the rotor forging following the forging step;

identifying an axial line through the rotor forging that is more centrally located with respect to material properties of the rotor forging than the geometric centerline of the rotor forging; and then

machining the rotor forging to produce a machined rotor containing first and second rotor regions and a transition zone therebetween corresponding to the first and second forging regions and the transition zone of the rotor forging such that the first and second rotor regions are formed of the different alloys and the transition zone of the machined rotor has a composition that differs from and varies between the first and second rotor regions, wherein the machining step is performed so that the axial line of the rotor forging defines an axis of rotation of the machined rotor, the machined rotor exhibiting less deflection when heated to an elevated temperature than would the machined rotor if machined so that the geometric centerline thereof defined the axis of rotation of the machined rotor and the machined rotor were heated to the elevated temperature.

[c2] 2. The process according to claim 1, further comprising heat treating the first and second forging regions to different temperatures after the forging step and before the machining step.

[c3] 3. The process according to claim 1, further comprising the steps of:

producing a rotor forging specimen in accordance with the casting and forging steps of claim 1, whereby the rotor forging specimen contains first and second specimen regions and a transition zone therebetween, the first and second specimen regions are formed of the different alloys, the transition zone of the rotor forging specimen has a composition that differs from and varies between the first and second specimen regions, and the first and second specimen regions and the transition zone therebetween are axially aligned along a geometric centerline of the rotor forging specimen;

ascertaining boundary points of the transition zone within the rotor forging specimen to define a plurality of two-dimensional cross-sectional shapes of the transition zone;

using the plurality of two-dimensional cross-sectional shapes to produce a three-dimensional approximation of the shape of the transition zone within the rotor forging specimen; and

using the three-dimensional approximation of the shape of the transition zone within the rotor forging specimen to identify the axial line of the rotor forging.

[c4] 4. The process according to claim 3, wherein the step of

identifying the axial line of the rotor forging comprises determining at an outside surface of the rotor forging the level of at least one alloying constituent of at least one of the different alloys of the first and second specimen regions.

[c5] 5. The process according to claim 1, wherein the step of identifying the axial line through the rotor forging comprises producing a three-dimensional approximation of the shape of the transition zone within the rotor forging by ultrasonically examining the rotor forging.

[c6] 6. The process according to claim 1, wherein the first rotor region is located within a high pressure region of the machined rotor and is formed from an alloy chosen from the group consisting of CrMoV low alloy steels, martensitic stainless steels containing about 9 to about 14 weight percent chromium, Fe-Ni alloys, and nickel-base alloys, and the second rotor region is located within a low pressure region of the machined rotor and is formed from an alloy chosen from the group consisting of NiCrMoV low alloy steels and martensitic stainless steels containing about 11 to about 14 weight percent chromium.

[c7] 7. The process according to claim 1, wherein the casting step comprises a consumable electrode remelting tech-

nique and uses an electrode having a first section and a second section contacting the first section, the first section corresponding in composition to the first ingot region and the second section corresponding in composition to the second ingot region.

[c8] 8. The process according to claim 1, wherein the casting step comprises a consumable electrode remelting technique and uses an electrode having a first section corresponding in composition to the first ingot region, a second section corresponding in composition to the second ingot region, and an intermediate section between the first and second sections and having a composition that differs from the compositions of the first and second sections of the electrode.

[c9] 9. The process according to claim 8, wherein the composition of the first section of the electrode is a CrMoV low alloy steel, the composition of the second section of the electrode is a NiCrMoV low alloy steel, and the composition of the intermediate section of the electrode consists of, by weight, about 0.25 to about 8% nickel, about 0.8 to about 6% chromium, about 0.2 to about 1.0% manganese, about 0.2 to about 1.5% molybdenum, about 0.05 to about 0.35% vanadium, about 0.1 to about 0.4% carbon, the balance iron and incidental impurities.

[c10] 10. The process according to claim 8, wherein the composition of the first section of the electrode is a martensitic stainless steel containing about 11 to about 14 weight percent chromium, the composition of the second section of the electrode is a NiCrMoV low alloy steel, and the composition of the intermediate section of the electrode consists of, by weight, about 4 to about 8% nickel, about 14 to about 30% chromium, up to about 1% manganese, about 1.5 to about 5% molybdenum, about 3 to about 7% tungsten, about 4 to about 12% cobalt, about 0.2 to about 0.35% carbon, the balance iron and incidental impurities.

[c11] 11. The process according to claim 8, wherein the composition of the first section of the electrode is a Fe-NI alloy, the composition of the second section of the electrode is a NiCrMoV low alloy steel, and the composition of the intermediate section of the electrode consists of, by weight, about 16 to about 32% chromium, about 1 to about 4% manganese, about 1.5 to about 4% molybdenum, about 0.5 to about 5% titanium, up to about 0.5% aluminum, about 0.1 to about 1.0% vanadium, up to about 2% silicon, up to about 0.08% carbon, the balance nickel and incidental impurities.

[c12] 12. The process according to claim 8, wherein the composition of the first section of the electrode is a nickel-

base alloy, the composition of the second section of the electrode is a NiCrMoV low alloy steel, and the composition of the intermediate section of the electrode consists of, by weight, about 15 to about 40% chromium, up to about 0.35% manganese, about 2 to about 10% molybdenum, about 3 to about 12% niobium, up to about 3% titanium, up to about 2% aluminum, up to about 1% cobalt, up to about 20% iron, about 0.01 to about 0.08% carbon, the balance nickel and incidental impurities.

[c13] 13. The process according to claim 8, wherein the composition of the first section of the electrode is a martensitic stainless steel containing about 9 to about 14 weight percent chromium, the composition of the second section of the electrode is a martensitic stainless steel containing about 11 to about 14 weight percent chromium, and the composition of the intermediate section of the electrode consists of, by weight, about 0.5 to about 8% nickel, about 9 to about 18% chromium, up to about 4% manganese, about 0.8 to about 4% molybdenum, about 0.1 to about 0.5% vanadium, up to about 0.05% aluminum, about 0.02 to about 0.05 nitrogen, about 0.15 to about 0.35% carbon, the balance iron and incidental impurities.

[c14] 14. The process according to claim 8, wherein the composition of the first section of the electrode is a Fe-Ni al-

loy, the composition of the second section of the electrode is a martensitic stainless steel containing about 9 to about 14 weight percent chromium, and the composition of the intermediate section of the electrode consists of, by weight, up to about 60% nickel, about 9 to about 24% chromium, about 0.5 to about 2% manganese, about 0.5 to about 3% molybdenum, up to about 0.5% vanadium, about 0.10 to about 0.35% carbon, the balance iron and incidental impurities.

[c15] 15. The process according to claim 8, wherein the composition of the first section of the electrode is Alloy 718, the composition of the second section of the electrode is a martensitic stainless steel containing about 9 to about 14 weight percent chromium, and the composition of the intermediate section of the electrode consists of, by weight, about 8 to about 12% chromium, about 0.5 to about 1.2% manganese, up to about 2% molybdenum, about 0.2 to about 0.5% vanadium, up to about 1% cobalt, about 0.01 to about 0.2% carbon, the balance iron and incidental impurities.

[c16] 16. The process according to claim 8, wherein the composition of the first section of the electrode is Alloy 718, the composition of the second section of the electrode is a martensitic stainless steel containing about 9 to about 14 weight percent chromium, and the composition of the

intermediate section of the electrode consists of, by weight, about 9 to about 50% chromium, up to about 2% manganese, up to about 8% molybdenum, up to about 12% niobium, up to about 2% aluminum, up to about 3% titanium, up to about 1% cobalt, about 0.01 to about 0.08% carbon, the balance iron and incidental impurities.

[c17] 17. A process for producing a monolithic steam turbine rotor, the process comprising the steps of:
casting an ingot using a consumable electrode remelting technique to have at least first and second ingot regions axially aligned within the ingot, the first and second ingot regions being formed of different alloys that intermix during casting to define a transition zone between the first and second ingot regions, the transition zone having a composition that differs from and varies between the first and second ingot regions;
forging the ingot to produce a rotor forging containing first and second forging regions and a transition zone therebetween corresponding to the first and second ingot regions and the transition zone of the ingot such that the first and second forging regions are formed of the different alloys and the transition zone of the rotor forging has a composition that differs from and varies between the first and second forging regions, the first and second forging regions and the transition zone

therebetween being axially aligned along a geometric centerline of the rotor forging;

ascertaining boundary points of the transition zone within the rotor forging to define a plurality of two-dimensional cross-sectional shapes of the transition zone;

using the two-dimensional cross-sectional shapes of the transition zone to produce a three-dimensional approximation of the shape of the transition zone;

using the three-dimensional approximation to predict deflection of the geometric centerline of the rotor forging if the rotor forging were to be heated to an elevated temperature;

identifying an axial line through the rotor forging that is more centrally located with respect to material properties of the rotor forging and the three-dimensional approximation of the shape of the transition zone than the geometric centerline of the rotor forging; and then

machining the rotor forging to produce a machined monolithic rotor in which the axial line of the rotor forging defines an axis of rotation of the machined monolithic rotor, the machined monolithic rotor exhibiting less deflection at the elevated temperature than the deflection predicted for the rotor forging at the elevated temperature.

[c18] 18. The process according to claim 17, wherein the boundary points of the transition zone are ascertained by longitudinally sectioning a specimen of the rotor forging along the geometric centerline thereof and determining the level of at least one alloying constituent of at least one of the different alloys of the first and second forging regions.

[c19] 19. The process according to claim 17, wherein the boundary points of the transition zone are ascertained by ultrasonically examining the rotor forging along the geometric centerline thereof to determine variations in metallurgical characteristics of the first and second forging regions and the transition zone therebetween.

[c20] 20. The process according to claim 17, wherein the three-dimensional approximation of the shape of the transition zone of the rotor forging is asymmetrical about the geometric centerline of the rotor forging.

[c21] 21. The process according to claim 17, wherein as a result of the forging and machining steps the first ingot region defines a first rotor region located within a high pressure region of the machined monolithic rotor, and the second ingot region defines a second rotor region located within a low pressure region of the machined monolithic rotor, the first rotor region being formed

from an alloy chosen from the group consisting of Cr-MoV low alloy steels, martensitic stainless steels containing about 9 to about 14 weight percent chromium, Fe-Ni alloys, and nickel-base alloys, and the second rotor region being formed from an alloy chosen from the group consisting of NiCrMoV low alloy steels and martensitic stainless steels containing about 11 to about 14 weight percent chromium.

[c22] 22. The process according to claim 17, wherein the casting step comprises using an electrode having a first section corresponding in composition to the first ingot region, a second section corresponding in composition to the second ingot region, and an intermediate section between the first and second sections and having a composition that differs from the compositions of the first and second sections of the electrode.

[c23] 23. The process according to claim 17, further comprising the step of simultaneously heat treating the first and second forging regions at different temperatures.

[c24] 24. A monolithic rotor formed by machining a rotor forging, the monolithic rotor comprising first and second rotor regions axially aligned within the monolithic rotor and a transition zone therebetween, the first and second rotor regions being formed of different alloys and the

transition zone having a composition that differs from and varies between the first and second rotor regions, the transition zone having a three-dimensional shape about a centerline of the rotor forging, the monolithic rotor having an axis of rotation that is more centrally located with respect to the transition zone than the centerline of the rotor forging.

[c25] 25. The monolithic rotor according to claim 24, wherein the axis of rotation of the monolithic rotor is more centrally located with respect to material properties of the monolithic rotor than the centerline of the rotor forging.

[c26] 26. The monolithic rotor according to claim 24, wherein the first rotor region is located within a high pressure region of the monolithic rotor and is formed from an alloy chosen from the group consisting of CrMoV low alloy steels, martensitic stainless steels containing about 11 to about 14 weight percent chromium, Fe-Ni alloys, and nickel-base alloys, and the second rotor region is located within a low pressure region of the monolithic rotor and is formed from an alloy chosen from the group consisting of NiCrMoV low alloy steels and martensitic stainless steels containing about 11 to about 14 weight percent chromium.

[c27] 27. The monolithic rotor according to claim 24, wherein

the rotor is a steam turbine rotor.

[c28] 28. A steam turbine in which the monolithic rotor according to claim 27 is installed.

[c29] 29. The monolithic rotor according to claim 24, wherein the rotor is a gas turbine engine rotor.

[c30] 30. A gas turbine engine in which the monolithic rotor according to claim 29 is installed.

[c31] 31. The monolithic rotor according to claim 24, wherein the rotor is a jet engine rotor.

[c32] 32. A jet engine in which the monolithic rotor according to claim 31 is installed.